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THE CARBON-NITROGEN RATIOS IN SOME HAWAIIAN SOILS

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Decomposition of plant residues, from which the soil organic matter originates, is accompanied by a narrowing of the carbon-nitrogen ratio. As decomposition slows down, an equilibrium value is approached. McLean *(8)* noted that the value normally attained is about 10 to 12:1. Jenny *(5)* in his study, in Central United States, found that nitrogen decreased as the mean annual temperature increased. A. L. Dean *(3)* found that the relation between temperatures and nitrogen in Central United States could not be extended to include Hawaii. He also found that the carbon-nitrogen ratio in most Hawaiian soils is below 10:1 and more nearly 8:1. L. A. Dean *(4)* studied the effect of rainfall on carbon, nitrogen, and carbon-nitrogen ratio and showed a significant relationship that each increased with an increase in annual rainfall and elevation. The work of Ayres *(1)* showed that for the range of 25 to 180 inches of annual rainfall the carbon-nitrogen ratio varied from 9 to 20. Jenny *(6, 7)* in attempting to resolve the conflicting reports between his earlier work *(5)* and that of Dean *(3)*, Dean *(4)*, Ayres *(1)*, and others obtained results in Columbia, South America, that were similar to those obtained for similar conditions in Hawaii. He concluded that in the tropical regions favorable climatic condition and high annual rates of fixation of nitrogen, because of large numbers of legumes, are the primary causes of luxuriant vegetation. He also states that the decomposition of the forest floor that

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rests on the mineral soil proceeds at a rapid rate and a considerable part of the decomposition products infiltrate into the mineral soil. Decomposition within the mineral soil appears to be slow. Accordingly, humus rapidly accumulates to a high level.

This paper attempts to determine quantitatively carbon, nitrogen, and the carbon-nitrogen ratios of the soils of Hawaii and to show each in relation to the annual rainfall.

MATERIALS AND METHODS

The soils were selected to represent the major great soil groups and important soil series within these great soil groups. Four samples, one from each of four areas, were taken for each soil series. When possible, samples of virgin soils were taken. In some cases due to the extensive cultivation of the series, this was not possible. Since under tropical conditions decomposition is very rapid and controlled by climatic factors, all samples were selected on flat to gently sloping topography irrespective of exposure. All soils used in this study were clays, containing more than 60% clay. Only the surface soil, 0 to 8 inches, was used. Table 1 lists the soils sampled along with the rainfall and elevation at each sampling site. The temperature changes in Hawaii are mainly a function of the elevation, decreasing about 3 degrees Fahrenheit for each 1000-foot rise in elevation in local areas. The physical properties of the soils used are described in Cline *(2)*.

The bulk samples were air dried for a period of 2 weeks. Any large undecomposed organic matter, such as roots of living plants and surface trash, was removed as this was not considered part of the soil organic matter. The entire sample was then ground to pass a 20-mesh screen. This included any rock fragments that were present within the soil. The ground sample was then thoroughly mixed. A portion was removed and oven dried at 110° C. for at least 24 hours. The samples were then analyzed for carbon and nitrogen in duplicate and averaged.

Carbon was determined following the dry combustion method described by Piper *(9)* with the modification that bottled oxygen was blown through the combustion tube rather than air being drawn through.

Nitrogen was determined by the Kjeldahl method for soil nitrogen as described in the Methods of Analysis of the Association of Official Agricultural Chemists *(11)*.

RESULTS

The results of the analyses for carbon and nitrogen along with the calculated carbon-nitrogen ratios in the 52 soils sampled are shown in table 1. Plots of carbon vs rainfall, nitrogen vs rainfall, and carbon:nitrogen vs rain-

TABLE 1. List of 52 Hawaiian soils sampled including annual rainfall and elevation, carbon, nitrogen, and carbon-nitrogen ratio

Great soil group	Soil series	Rainfall (in inches)	Elevation (in feet)	Carbon percent	Nitrogen percent	C/N
Low Humic Latosol	Molokai	28*	120	1.71	0.148	11.54
		27*	150	1.42	0.152	9.37
		31	320	1.16	0.142	8.16
		23*	200	1.55	0.157	9.89
	Waipahu	22*	70	1.28	0.123	10.42
		21*	40	1.97	0.146	13.48
		26*	80	1.41	0.148	9.53
		25*	90	1.21	0.105	11.51
	Lahaina	27	540	2.15	0.204	10.54
		27	170	1.99	0.186	10.68
		27	140	1.79	0.172	10.39
		30	340	2.03	0.214	9.50
	Wahiawa	45*	920	1.37	0.118	11.42
		46*	480	3.25	0.338	9.61
		45*	480	2.84	0.310	9.16
		50*	440	4.80	0.403	11.92
	Kahana	64*	640	3.34	0.285	11.68
		60*	660	3.88	0.288	13.46
		56	610	1.82	0.194	9.39
		52*	640	4.42	0.238	18.56
Humic Latosol	Paaloa	45*	1000	3.41	0.220	15.52
		68*	1020	3.44	0.238	14.43
		70*	1200	3.45	0.308	11.21
		75*	840	3.15	0.201	15.66
	Kaneohe	83*	280	3.91	0.229	17.06
		90*	280	5.37	0.351	15.30
		70*	130	3.25	0.270	12.03
		83*	320	4.77	0.331	14.40
Hydrol Humic Latosol	Hilo	148*	100	5.89	0.334	17.62
		200*	1320	17.02	0.976	17.44
		140*	110	8.71	0.561	15.53
		140*	110	13.13	0.790	16.62
	Koolau	98*	1050	3.35	0.179	18.74
		95	1180	3.45	0.214	16.13
		90*	1280	3.71	0.252	14.73
		83*	1360	3.40	0.204	16.65
Humic Ferruginous Latosol	Kolekole	37*	840	4.24	0.254	16.69
		32*	840	2.77	0.234	11.83
		30*	760	4.08	0.298	13.71
		28*	720	5.68	0.380	14.95
	Puhi	80	280	3.83	0.269	14.24
		50	380	3.12	0.230	13.55
		60	380	3.10	0.256	12.11
		55	400	3.26	0.292	11.15

* Virgin soils

(Continued)

TABLE 1. *(Continued)*

Great soil group	Soil series	Rainfall (in inches)	Elevation (in feet)	Carbon percent	Nitrogen percent	C/N
Dark Magnesium Clay	Lualualei	25*	120	0.75	0.067	11.13
		20	70	1.00	0.088	11.39
		18*	60	0.88	0.088	9.94
		18	60	1.44	0.090	15.96
Gray Hydromorphic Soil	Honouliuli	19	30	0.47	0.067	6.96
		18	60	1.53	0.098	15.62
		34	20	2.16	0.164	13.18
		26	20	1.32	0.133	9.96

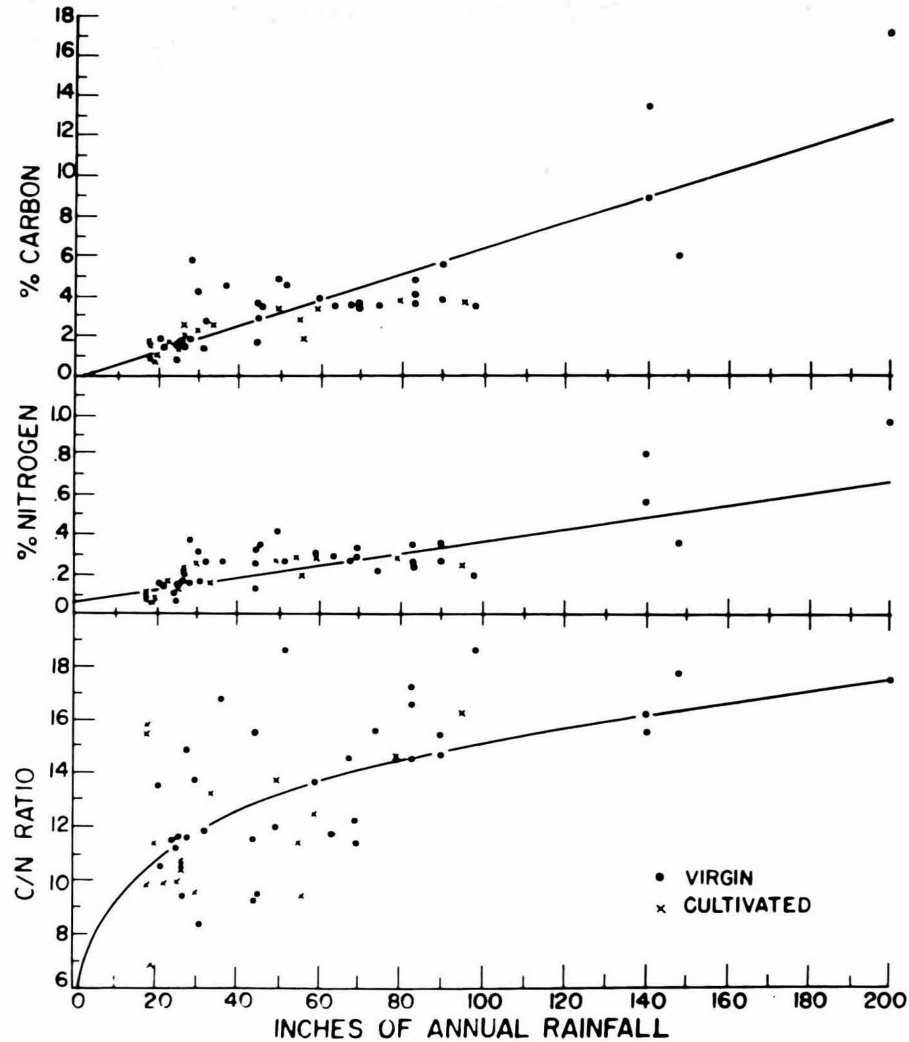
* Virgin soils

fall are shown in figure 1. Correlation analyses of carbon and rainfall, nitrogen and rainfall, and log carbon:nitrogen and log rainfall were made. The results are indicated in figure 1. Multiple regression analyses of carbon on rainfall and elevation, nitrogen on rainfall and elevation, and log carbon:nitrogen on log rainfall and elevation were made. In each case, rainfall was highly significant and elevation was nonsignificant.

DISCUSSION OF RESULTS

The organic matter content of the soil, as indicated by the carbon content, increased with increasing rainfall. This agrees with Ayres *(1)* and Jenny *(7)* that the natural vegetation is heavier and that the decomposition within the soil, receiving large amounts of annual rainfall, is impeded because of the higher amounts of water contained in these soils. In small areas there is a highly significant correlation between rainfall and elevation. In the area covered by this study the correlation was only significant. In this respect one can expect the organic matter in the soil to increase with increasing elevation even though there was no significant correlation between carbon content and elevation when taken alone.

As shown in figure 1, the scatter of carbon content, which is a measure of the organic matter content, with rainfall appears to be different for cultivated and virgin soils. A "t" test showed that above 60 inches of rainfall the cultivated soils had significantly less carbon than the virgin soils. In the lower rainfall region there was no significant difference. However, as pointed out by Cline *(2)* the cultivated soils in the low rainfall area generally have much higher organic matter than the virgin soils. These soils receiving below about 30 inches of rainfall in their virgin state had a sparse vegetation. But, under irrigated cultivation more organic matter is returned to the soil, thereby increasing the carbon content. In higher rainfall regions the opposite is true. That is, less organic matter is added to the surface of the cultivated



CURVE	REGRESSION EQUATIONS	CORRELATION COEFFICIENTS	MEANS
CARBON	$C = 0.063R - 0.105$	$r = 0.847^{**}$	$3.35 \pm 0.42\%$
NITROGEN	$N = 0.003R + 0.061$	$r = 0.796^{**}$	$0.245 \pm 0.031\%$
C/N RATIO	$\log C/N = 0.217 \log R + 0.742$	$r = 0.585^{**}$	1.100 ± 0.023

FIG. 1. Relation between carbon content and rainfall, nitrogen content and rainfall, and carbon-nitrogen ratio and rainfall of 52 Hawaiian soils.

soils than in virgin soils, and cultivation helps to aerate the soil and aid the decomposition of the existing soil organic matter.

Nitrogen also increases with rainfall but at a slower rate than does carbon. This phenomenon is to be expected because as the rainfall increases, the vegetation becomes more luxuriant and larger amounts of fresh material are added to the surface. Decomposition under these wetter conditions is also slower. Even though the decomposition is slower the nitrogen that is mineralized is leached more rapidly in the high rainfall regions. Therefore, it is to be expected that the carbon-nitrogen ratio will increase to equilibrium values that will be closer to the carbon-nitrogen ratio of the fresh plant material. It can be discerned then that with increasing annual rainfall not only does nitrogen content increase but also the carbon-nitrogen ratio. The fact that the carbon-nitrogen ratio does increase with increasing rainfall is indicated in figure 1. However, the increment of increase of the carbon-nitrogen ratio is less with each increment of increase in rainfall.

Figure 1 indicates a similar characteristic for nitrogen of cultivated and virgin soils as for carbon. Since both carbon and nitrogen are affected similarly, the carbon-nitrogen ratio should not be affected and the carbon-nitrogen ratio for cultivated soils should be no different than that for virgin soils. The graph of carbon:nitrogen in figure 1 shows that there is no appreciable difference in the carbon:nitrogen ratio between cultivated and virgin soils. The results of Ayres *(1)* for carbon-nitrogen ratios in the high rainfall area agree very well with that shown in figure 1.

In the regions of high rainfall, the high carbon-nitrogen ratio does not seem to adversely affect the growth of native vegetation. A large proportion (probably over 40 percent) of these tropical and semitropical plants are legumes and therefore are partially able to "fix" their own nitrogen and supply nitrogen to the adjacent nonleguminous plants. This aids also in the build-up of organic matter to high levels in many of these soils. Ten to 20 percent or higher organic matter is common in these tropical rain forest type soils.

There are then, in the rain forest type soils of the tropics, equilibrium values of carbon-nitrogen ratios that will not adversely affect plant growth. The organic matter content will not be maintained in the cultivated soils to the same level as in the virgin soils because of the added aeration due to manipulation of the soil. Also, most crop plants will not supply sufficient nitrogen to maintain the organic matter at a high level.

SUMMARY

Both carbon and nitrogen increase with increasing rainfall. The cultivated soils in regions of rainfall below 30 inches have more carbon and nitrogen than the virgin soils. In regions of rainfall above 60 inches the cultivated soils have less carbon and nitrogen than corresponding virgin soils. This

phenomenon is associated with the amounts of plant residues returned to the soil by crops or native vegetation.

The carbon-nitrogen ratio increases logarithmically with increasing rainfall. There is no difference in the carbon-nitrogen ratio of cultivated and virgin soils of similar rainfall areas. The large number of leguminous plants is probably the main reason why the native plant growth is not hindered by the high carbon-nitrogen ratio and subsequent nitrogen availability.

The high amounts of organic matter in the soils of the high rainfall areas aid in the maintenance of the soil structure which allows large amounts of water to enter the soil. This large quantity of water produces a semianaerobic condition that hinders decomposition and maintains the organic matter and the carbon-nitrogen ratio at high levels.

There were no significant correlations between the elevation and carbon content, nitrogen content, and carbon-nitrogen ratio.

LITERATURE CITED

1. AYRES, A. S. 1943. Soils of the high-rainfall areas in the Hawaiian Islands., Hawaii Agr. Expt. Sta. Tech. Bul. 1.
2. CLINE, M. G. 1955. Soil Survey of the Territory of Hawaii. U.S.D.A. series 1939, No. 25.
3. DEAN, A. L. 1930. Nitrogen and organic matter in Hawaiian pineapple soils. Soil Sci. 30:439-42.
4. DEAN, L. A. 1938. The effect of rainfall on carbon and nitrogen contents and carbon:nitrogen ratios of Hawaiian soils. Soil Sci. Soc. Am. Proc. 2:455-9.
5. JENNY, HANS. 1928. Relation of temperature to the amount of nitrogen in soils. Soil Sci. 27:169-188.
6. ____________, F. BINGHAM, and B. PADILLA-SARARIA. 1948. Nitrogen and organic matter contents of equatorial soils of Columbia, South America. Soil Sci. 66:173-86.
7. ____________. 1950. Causes of the high nitrogen and organic matter contents of certain tropical forest soils. Soil Sci. 69:63-69.
8. McLEAN, W. 1930. The carbon-nitrogen ratio of soil organic matter. Jour. Agr. Sci. 20:348-54.
9. PIPER, C. S. 1942. Soil and plant analysis. Interscience Publishers, Inc., New York. Pp. 216-223.
10. SNEDECOR, G. W. 1956. Statistical Methods. Iowa State College Press, Ames, Iowa.
11. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. 1955. Official methods of analysis. 8th ed. Washington, D. C.

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